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ABSTRACT

Situational Force Scoring is routinely used for combined-arms combat adjudication. This paper asserts that there is a basic problem with Situational Force Scoring due to its use of aggregation and disaggregation. Examples are used to show that in certain limiting situations, nonsensical attrition results are predicted. A simple alteration is suggested and the approaches are compared for a typical application whereby optimal force structures are sought. For several situations both approaches suggest identical or similar solutions, although the resulting attrition display a lower level of correlation. Importantly, however, in some situations the new approach suggests somewhat different results. A game theory analysis is also provided to illustrate the potential use of such models in estimating robust force allocations.

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Executive Summary

The recent Defence Capability Review (October 2003) reinforced the importance of combined arms in land combat:

> 'The government has in particular accepted the advice of the Chief of Army that the combined arms approach - whereby infantry, armour, artillery, aviation and engineers work together to support and protect each other - remains the best way of achieving rapid success while minimising friendly casualties.'

To conduct studies, experiments or analyses of land combat one therefore needs to ensure that modelling and simulations adequately capture the synergistic nature of combined arms. For combined arms conflict adjudication, two main approaches have been developed over the past two decades, the Quantified Judgement Model (QJM) and Situational Force Scoring (SFS). Both have strengths and weaknesses and both have been utilized in studies or other models (for example, Harpoon 4 Ground Combat for the QJM and the Joint Integrated Contingency Model (JICM) for SFS).

A combined arms adjudication simulation, the Land Combat Adjudication Model (LCAM), is being developed by DSAD. This model is based on the method of SFS for estimating attrition, and improves upon prior DSAD modelling efforts.

This paper asserts that there is a basic problem that SFS has due to its use of aggregation and disaggregation. Specifically, the degree of imbalance in the anti-armour and anti-infantry capabilities of each side appears to be lost or distorted when a single aggregated Force Ratio is used to compute a total attrition which is then disaggregated into component attrition. Examples are used to show that in certain limiting situations, nonsensical attrition results are predicted.

A simple alteration is suggested and the approaches are compared for a typical application whereby optimal force structures are sought. For several situations both approaches suggest identical or similar solutions, although the resulting attrition displays a lower level of correlation. Importantly, however, in some situations the new approach suggests somewhat different results. A game theory analysis is also provided to illustrate the potential use of such models in estimating robust force allocations.

Ultimately, a validation effort will be required to determine the true extent of the appropriateness of each approach, though it is asserted here that the new approach appears to predict attrition more in line with expectations logically drawn from the underlying data.

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Andrew Gill graduated from James Cook University of North Queensland with a BSc majoring in Mathematics in 1991 and a PhD in Applied Mathematics in 1995. Dr Gill worked as an Associate Lecturer in the Applied Mathematics Department at Adelaide University before joining DSTO in 1998 as a research scientist in Land Operations Division before transferring to the Defence Systems Analysis Division in 2001. His research interests are in the development and application of classical military operations analysis mathematical methods to support seminar-wargaming for concept development.

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1. Introduction

The recent Defence Capability Review (October 2003) reinforced the importance of combined arms in land combat:

> 'The government has in particular accepted the advice of the Chief of Army that the combined arms approach - whereby infantry, armour, artillery, aviation and engineers work together to support and protect each other - remains the best way of achieving rapid success while minimising friendly casualties.'

as well as the enduring need for armour:

> 'The Government has decided that to provide our land forces with the combat weight they need within combined arms will require the replacement of Australia's ageing Leopard tanks.'

To conduct studies, experiments or analyses of land combat one therefore needs to ensure that modelling and simulations adequately capture the synergistic nature of combined arms.

Traditionally, DSTO has used and relied upon high-resolution simulations and wargames to assist in these endeavours (for example, the use of Janus, CAEn and CASTFOREM as part of the Army Experimental Framework and the Headline Experiments).

More recently however, there has been a shift towards using lower-resolution simulations and seminar-wargames to enable exploration of a greater region of the scenario space (for example, the Headline Experiments during 2002). The drivers for this change are an increasingly uncertain strategic environment and an emphasis on future warfighting concepts that contain more degrees of freedom. The impact of these drivers is also more obvious globally, with the development and use of 'exploratory analysis' [1] and multi-scenario analysis [2].

For combined arms conflict adjudication of this type, two main approaches have been developed over the past two decades, the Quantified Judgement Model (QJM) [3] and Situational Force Scoring (SFS) [4]. Both have strengths and weaknesses and both have been utilized in studies or other models (for example, Harpoon 4 Ground Combat for the QJM [5] and the Joint Integrated Contingency Model (JICM) for SFS [6]).

While an in-depth comparison of the appropriateness of the two approaches is not the aim of this paper, it is argued that it appears that SFS more explicitly models the combined arms synergies, which is supported by [7]:

'The mobility equation more specifically addresses the advantage gained by a more mobile (and armor heavy force) over a less mobile one. Beyond that, there is nothing to address the value of the "synergistic" effects of weapons.'

A combined arms adjudication simulation, the Land Combat Adjudication Model (LCAM), is being developed by DSAD [8]. This model is based on the method of SFS for estimating attrition, and improves upon prior DSAD modelling efforts [9].

This paper will show that there is a basic problem that SFS has due to its use of aggregation and disaggregation. First, the various steps of the SFS process are explained in Section 2. The problem will then be illustrated via simple combined arms versus infantry examples in Section 3. A proposed solution will be offered and analysed in Section 4. A comparison of the two approaches when used for a typical analysis is made in Section 5, and conclusions are drawn in Section 6.

2. Situational Force Scoring

Explanation of the steps involved will be easier by way of example. While SFS deals (in more or less detail) with armour, infantry, artillery, attack helicopters and air defence, we will restrict our attention to the manoeuvre elements of armour and infantry to simplify the explanation. Figure 1 below details the various key steps involved in computing attrition to the armour and infantry assets of both sides of an engagement.

Step 1. The number of armour and infantry assets is listed for both sides. Here we are giving the attacker a mix of 20 tanks and 333 infantry (approximately two armoured squadrons and one infantry battalion) while the defender consists solely of 667 infantry (approximately two infantry battalions).

Step 2. Each asset is given a numerical score to reflect its basic strength. Tables of asset scores have been produced for a large number of assets. Here we assign a value of 2.5 for each tank and 0.15 for each infantry. For simplicity, we have assumed the assets on either side are identical, but this needn't be the case (for example, an Abrams tank might be given a larger score than a T-72, or infantry scores may be different to reflect different levels of training or professionalism).

Step 3. The number of assets is multiplied by the asset score to obtain the Raw Strength of each asset. With the values given above, the Raw Strengths for the attacker are 50 for armour and infantry and 100 for the defender's infantry. Thus, the numbers in Step 1 were chosen so that both sides have a total of 100 Raw Strength points, but with different distributions among the manoeuvre forces.

Step 4. The Raw Strengths are then modified to reflect situation specific circumstances. The modification is via a multiplier to the Raw Strength and the two situations

considered are the type of terrain the battle is being fought on and the type of battle being fought.

Step 4a. Terrain is known to affect the performance and outcome of battles. Terrain is generally expressed in various levels of denseness or complexity, ranging from 'open' or desert conditions through to 'closed' or jungle. Urban terrain, while not simply lying on this one axis, is also generally included. Terrain generally favours the defender and affects the manoeuvre forces differently (for example, armour is more effective in open terrain, while infantry favour close combat). For simplicity, and as the focus of this paper is not on this step, we will assume the Terrain Multiplier to equal one for both the attacker and defender and for both armour and infantry assets.

Step 4b. As with terrain, the type of battle being fought affects the performance of the assets of both sides. Battle types generally express the level of preparations conducted by the attacker and the level of protective measures taken by the defender (for example, a hasty attack against a prepared defense). For the same reasons as above, we will assume the Battle Type Multiplier to equal one for both the attacker and defender and for both armour and infantry assets.

Step 5. The Raw Strength of each asset is multiplied by the Terrain Multiplier and Battle Type Multiplier to obtain the Situational Strength of each asset. With the values given above, the Situational Strengths for the attacker are 50 for armour and infantry and 100 for the defender's infantry.

Step 6. The Armour Situational Strength is then adjusted to reflect any imbalance regarding the infantry support to armour assets. The modification is via a multiplier to the Armour Situational Strength.

Step 6a. This adjustment is related to the concept of density as described in Soviet doctrine and suggests that armour is less effective if sufficient infantry is not present to support it. This sufficiency is given as a multiple (or fraction) of the Armour Situational Strength, and varies with the terrain type (with greater support required in close terrain). Here, the Required Multiple is taken as 0.16 for both the attacker and defender.

Step 6b. The amount of infantry available, as a Proportion of the Requirement, is then calculated. For the attacker, there is 50 points of infantry with a requirement of 0.16* Armour Situational Strength =0.16*50=8. Thus, the Proportion of the Requirement for the attacker is 50/8=6.25. For the defender, there is 100 points of infantry with a requirement of 0.16* Armour Situational Strength =0.16*0=0. Thus, the Proportion of the Requirement for the attacker is 100/0=INFTY.

Step 6c. The Proportion of the Requirement is used to determine whether a penalty (via a multiplier) should be applied to the Armour Situational Strength. If the Proportion of the Requirement is less than one, then a linear function, defined by the

Shortage Intercept, is used to compute the penalty. Again, this Shortage Intercept varies with the terrain type (with a smaller Shortage Intercept, which implies a harsher penalty, in open terrain). Here, the Shortage Intercept is taken as 0.38 for both the attacker and defender.

Step 6d. The Shortage Multiplier is then computed for both the attacker and defender using the Shortage Intercept and the Proportion of the Requirement via the equation:

Shortage Multiplier = MINIMUM(1, Shortage Intercept + [1 - Shortage Intercept]* Proportion of the Requirement)

Here, both the attacker and defender have sufficient infantry supporting their armour assets (reflected by a Proportion of the Requirement greater than one) and thus the Shortage Multiplier is equal to one.

Step 7. The Armour Situational Strength is multiplied by the Shortage Multiplier to obtain the Armour Adjusted Strength (the Infantry Adjusted Strength is equal to the Infantry Situational Strength). With the values given above, the Adjusted Strengths for the attacker are 50 for armour and infantry and 100 for the defender's infantry.

Step 8. The true value of SFS in modelling combined arms starts with this step. It introduces the concept of Anti-Strengths, which captures the notion that the true strength of an asset is its ability to damage its targets. Armour is effective against both armour (anti-armour) and infantry (anti-infantry). Infantry (riflemen, not those armed with anti-tank weapons) are not very effective against armour but are effective against other infantry.

Step 8a. The Anti-Strength Multipliers of armour are given here. Tables of Anti-Strength Multipliers have been produced for a large number of assets. Here we assign a value of 1.0 for Armour Anti-Armour Strength Multiplier and 0.80 for Armour Anti-Infantry Strength Multiplier. Again, for simplicity, we have assumed the assets on either side are identical, but this needn't be the case (for the same reasons given in Step 2).

Step 8b. The Anti-Strength Multipliers of infantry are given here. Here we assign a value of 0.02 for Infantry Anti-Armour Strength Multiplier and 1.0 for Infantry Anti-Infantry Strength Multiplier, for both the attacker and defender.

Step 9. Finally, the Anti-Strengths are calculated. The Anti-Armour Strength is the weighted sum of the Adjusted Strengths with weights given by the Anti-Armour Strength Multiplier. Here, the attacker's Anti-Armour Strength= Armour Anti-Armour Strength Multiplier*Armour Adjusted Strength + Infantry Anti-Armour Strength Multiplier*Infantry Adjusted Strength = 1.0*50+0.02*50=51. Similarly, the attacker's Anti-Infantry Strength= Armour Anti-Infantry Strength Multiplier*Armour Adjusted Strength + Infantry Anti-Infantry Strength Multiplier*Infantry Adjusted Strength =

0.8*50+1.0*50=90. Similar calculations for the defender yield Anti-Armour Strength=2.0 and Anti-Infantry Strength=100.

Step 10. The Adjusted Strengths for each side, calculated in Step 7, are then modified to reflect any imbalance regarding the Anti-Strengths of each side's assets, relative to the Adjusted Strengths of the enemy. The modification is via a divisor to the Adjusted Strengths of the enemy.

Step 10a. This modification is related to the "3:1" concept of force parity, but differentiated by individual combat arm. The requirement is given as a multiple of the enemy's Adjusted Strength, and varies with the terrain type, combat arm and whether one is attacking or defending (with a greater requirement in open terrain, anti-armour, and for the attacker). Here, the Required Multiple is taken as 2.0 for the attacker's Anti-Armour and Anti-Infantry, and 1.0 and 0.8 for the defender's Anti-Armour and Anti-Infantry Required Multiples, respectively.

Step 10b. The amount of each side's Anti-Strengths, as a Proportion of the Requirement, is then calculated. For the attacker, there is 51 points of Anti-Armour Strength with a requirement of 2.0* Enemy Armour Adjusted Strength =2.0*0=0. Thus, the Proportion of the Requirement for the attacker's Anti-Armour is 51/0=INFTY. Similarly, the Proportion of the Requirement for the attacker's Anti-Infantry is 90/(2.0*100)=0.45. For the defender, the Proportion of the Requirement for Anti-Armour is 2.0/(0.5*50)=0.08, and the Proportion of the Requirement for Anti-Infantry is 100/(1.0*50)=2.0.

Step 10c. The Proportion of the Requirement is used to determine whether a penalty (via a divisor) should be applied to the Adjusted Strengths. If the Proportion of the Requirement is less than one, then linear functions, defined by the Shortage Intercepts, are used to compute the penalty. These Shortage Intercepts vary with the terrain type and between attacker and defender (with smaller Shortage Intercepts, which imply harsher penalties, in open terrain, and for the attacker). Here, the Shortage Intercepts are taken as 0.17 for Anti-Armour and 0.38 for Anti-Infantry for the attacker and 0.29 for Anti-Armour and 0.38 for Anti-Infantry for the defender.

Step 10d. The Shortage Divisor is then computed for both the attacker and defender using the Shortage Intercepts and the Proportion of the Requirement via the equation:

Shortage Divisor = MINIMUM(1, Shortage Intercept + [1 - Shortage Intercept]* Proportion of the Requirement)

Here, the attacker has sufficient Anti-Armour and the defender has sufficient Anti-Infantry, so that the Shortage Divisors are equal to one in these cases. However, the attacker has insufficient Anti-Infantry (Proportion of the Requirement being 0.45) and thus the attacker's Anti-Infantry Shortage Divisor = MINIMUM(1,0.38+[1-

0.38]*0.45)=0.66. Similarly, the defender's Anti-Armour Shortage Divisor = MINIMUM(1,0.29+[1-0.29]*0.08)=0.35.

Step 11. Each side's Adjusted Strengths are then divided by the corresponding enemy's Shortage Divisor to obtain the Final Strengths. Thus, since the attacker is short of Anti-Infantry (Proportion of the Requirement = 0.45) the defender's Infantry Adjusted Strength is improved by dividing by the attacker's Anti-Infantry Shortage Divisor. Thus the defender's Infantry Final Strength = 100/0.66 = 151.74. The defender's Armour Final Strength is unchanged (the attacker has at least the requirement) at 0.0. Also, since the defender is short of Anti-Armour (Proportion of the Requirement = 0.08) the attacker's Armour Adjusted Strength is improved by dividing by the defender's Anti-Armour Shortage Divisor. Thus the attacker's Armour Final Strength = 50/0.35 = 142.87. The attacker's Infantry Final Strength is unchanged (the defender has at least the requirement) at 50.0. The final step is to add the component Final Strengths to arrive at a Total Final Strength. For the attacker, this is 142.87+50.0=194.18. For the defender, this is 0.0+151.74=151.74.

Step 12. The Total Final Strengths of both sides are then compared to produce a Force Ratio. The Force Ratio for a side is defined as the Total Final Strength of that side divided by the Total Final Strength of the enemy. Thus the Force Ratio of each side is the reciprocal of the Force Ratio of the enemy. Here, for the attacker the Force Ratio is given by 194.18/151.74 = 1.28 and the Force Ratio for the defender is given by 151.74/194.18 = 0.78. We can now begin to understand how situational and tactical factors can affect the performance of forces. Both sides were given assets that yielded a Total Raw Strength of 100. However, the attacker has a deficiency in Anti-Infantry capability while the defender has a greater deficiency in Anti-Armour capability. The greater deficiency of the defender therefore resulted in a poorer Force Ratio for that side.

Step 13. The Force Ratios are then used to compute the total amount of attrition suffered by both sides.

Step 13a. First, the Percentage Strength Lost by both sides is computed. A power law formula is used in this calculation. The power law used for each side is:

Percentage Strength Lost = MINIMUM[1,0.135*POWER(Force Ratio,-0.93)]

Thus, for the attacker, the Percentage Strength Lost = MINIMUM[1,0.135*POWER(1.28,-0.93)] = 10.73%, while for the defender the Percentage Strength Lost = MINIMUM[1,0.135*POWER(0.78,-0.93)] = 16.98%. The use of the MINIMUM function is required since power laws are not constrained to be less than 100%.

Step 13b. The Percentage Strength Lost is then converted into Total Points Lost to allow distribution among the components (i.e. armour and infantry). The Total Points

Lost is based on the Total Final Strengths (not on the Raw Scores). Thus, for the attacker the Total Points Lost = (10.73/100)*194.18 = 20.84, while for the defender the Total Points Lost = (16.98/100)*151.74 = 25.77.

Step 14. The next step is to distribute these total losses into losses of armour and infantry. This is achieved using a Participation Factor and the Total Points Lost above.

Step 14a. The Participation Factor attempts to capture the historical or doctrinal evidence that suggest that different weapons are destroyed at different rates. A look-up table which varies with the attacker and defender, type of battle and primary assault weapons is used to generate the Participation Factor. The primary assault weapon differentiates between sides that 'lead with armour' and 'lead with infantry'. Here, the Participation Factor values used for the attacker are 1.5 for armour and 1.0 for infantry, and 1.2 for armour and 1.0 for infantry for the defender.

Step 14b. These Participation Factors and the Situational Strengths are used to compute the Relative Category Losses for both sides as a percentage. The equations used are:

Relative Armour Losses = Armour Participation Factor * Armour Situational Strength/[Armour Participation Factor * Armour Situational Strength + Infantry Participation Factor * Infantry Situational Strength]

Relative Infantry Losses = Infantry Participation Factor * Infantry Situational Strength/[Armour Participation Factor * Armour Situational Strength + Infantry Participation Factor * Infantry Situational Strength]

Here, this yields Relative Armour Losses = 1.5*50/[1.5*50+1.0*50] = 60% and Relative Infantry Losses = 1.0*50/[1.5*50+1.0*50] = 40% for the attacker, and Relative Armour Losses = 1.2*0/[1.2*0+1.0*100] = 0% and Relative Infantry Losses = 1.0*100/[1.2*0+1.0*100] = 100% for the defender (obvious, since the defender only has infantry).

Step 14c. These Relative Category Losses are then easily converted into Category Points Lost using the Total Points Lost of Step 13b. Here, for the attacker there are (60/100)*20.84 = 12.51 Armour Points Lost and (40/100)*20.84 = 8.34 Infantry Points Lost, while for the defender there are (0/100)*25.77 = 0 Armour Points Lost and (100/100)*25.77 = 25.77 Infantry Points Lost.

Step 15. The final step is to calculate the percentage of the original assets lost and then the rounded (integer) number of assets lost and remaining. The percentage is computed as the Category Points Lost as a fraction of the Final Strengths. Here, for the attacker the percentage armour losses is 12.51/144.18 = 8.67% and the percentage infantry losses is 8.34/144.18 = 16.67%, while for the defence the percentage armour losses is 0/0 = 0% (the correct interpretation) and the percentage infantry losses is 25.77/151.74 = 16.98%.

Step 15a. The percentage assets lost are converted into assets lost. For the attacker the number of armour assets lost is ROUND[(8.67/100)*20] = 2 and the number of infantry assets lost is ROUND[(16.67/100)*333] = 56. For the defender the number of armour assets lost is ROUND[(0/100)*0] = 0 and the number of infantry assets lost is ROUND[(16.98/100)*667] = 113.

Step 15b. Finally, the number of remaining assets for each side is computed. For the attacker the number of armour assets remaining is 20 – 2 = 18 and the number of infantry assets remaining is 333 – 56 = 278. For the defender the number of armour assets remaining is 0 – 0 = 0 and the number of infantry assets remaining is 667 – 113 = 553.

		ATTACKER					DEFENDER				
Step	**Description**	**Tanks**	**Infantry**	**Total**	**Anti-Tank**	**Anti-Infantry**	**Tanks**	**Infantry**	**Total**	**Anti-Tank**	**Anti-Infantry**
1	**Number of Assets**	**20**	**333**				**0**	**667**			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		**6.25**					**999.00**			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				51.00	90.00				2.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				**999.00**	**0.45**				**0.08**	**2.00**
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.66				0.35	1.00
11	**Final Strength**	144.18	50.00	194.18			0.00	151.74	151.74		
				Total					Total		
12	**Force Ratio (Strength or Anti-Strength)**			**1.28**					**0.78**		
13	Total Losses										
13a	**Percentage Strength Lost**			10.73%					16.98%		
13b	Total Points Lost			20.84					25.77		
		Old SFS					Old SFS				
14	**Absolute Category Losses**	Tanks	Infantry	Total			Tanks	Infantry	Total		
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	12.51	8.34	20.84			0.00	25.77	25.77		
		Tanks	Infantry				Tanks	Infantry			
15	**Percentage Category Losses**	**8.67%**	**16.67%**				**0.00%**	**16.98%**			
15a	**Assets Lost by Category**	2	56				0	113			
15b	**Assets Remaining**	18	278				0	553			

Figure 1 Key Steps of SFS Process of Adjudicating Combat Between Manoeuvre Forces

3. Problem with Situational Force Scoring

On initial inspection, the above process appears to be logical. The key steps regarding combined arms modelling are Steps 6 – 11. From Step 10b, we note that the attacker has less than one half of the required anti-infantry capability and inflicts only 17% attrition on the defender's infantry while the defender has less than one-tenth of the required anti-armour capability and inflicts only 9% attrition on the attacker's armour. If these are generally somewhat high or low, then they can be calibrated by changing the form of the attrition power law in Step 13.

However, it is interesting to compare the results when the Infantry Anti-Armour Strength Multiplier of the defender is changed from 0.02 to 0.0. That is, defending infantry are totally ineffective against the attacker's armour. In this situation, the defender has no anti-armour capability and therefore one should expect no armour losses to the attacker.

		ATTACKER					DEFENDER				
Step	Description	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry
1	Number of Assets	20	333				0	667			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	Raw Strength	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	Situational Strength	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	Proportion of Requirement		6.25					999.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	Adjusted Strength	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.8				1	0.8
8b	Infantry				0.02	1				0	1
9	Anti-Strength				51.00	90.00				0.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	Proportion of Requirement				999.00	0.45				0.00	2.00
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.66				0.29	1.00
11	Final Strength	172.41	50.00	222.41			0.00	151.74	151.74		
				Total					Total		
12	Force Ratio (Strength or Anti-Strength)			1.47					0.68		
13	Total Losses										
13a	Percentage Strength Lost			9.46%					19.26%		
13b	Total Points Lost			21.04					29.23		
		Old SFS					Old SFS				
14	Absolute Category Losses	Tanks	Infantry	Total			Tanks	Infantry	Total		
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	12.62	8.42	21.04			0.00	29.23	29.23		
		Tanks	Infantry				Tanks	Infantry			
15	Percentage Category Losses	7.32%	16.83%				0.00%	19.26%			
15a	Assets Lost by Category	1	56				0	128			
15b	Assets Remaining	19	277				0	538			

Figure 2 Example Showing Attacker Armour Losses when no Anti-Armour Capability rests with the Defender

However, Figure 2 indicates that this is not the case. Step 9 correctly records the fact that the defender has 0.0 as the Proportion of the Requirement for anti-armour, but Step 15 shows that 7.32% of the attacker's armour assets are lost. Unfortunately, there is no way the attrition power law can be tuned to correct for this.

On closer inspection one might suggest that the Shortage Divisor is not harsh enough and can be improved by reducing the Shortage Intercept in Step 10c. The most that this can be reduced is to have the value of zero, which will then have the effect of increasing the attacker's Armour Final Strength to 50/0=INFTY (for the sake of Excel this is approximated by 9999 to avoid divide by zero errors). Figure 3 shows that while the attacker's armour losses are indeed reduced to near zero, this change also has the undesired effect of increasing the defender's infantry losses (from 17%) to 100%.

		ATTACKER					DEFENDER				
Step	Description	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry
1	**Number of Assets**	20	333				0	667			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		6.25					999.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.8				1	0.8
8b	Infantry				0.02	1				0	1
9	**Anti-Strength**				51.00	90.00				0.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				9999.00	0.45				0.00	2.00
10c	Shortage Intercept				0.17	0.38				0.00	0.38
10d	Shortage Divisor				1.00	0.66				0.00	1.00
11	**Final Strength**	9999.00	50.00	10049.00			0.00	151.74	151.74		
12	**Force Ratio (Strength or Anti-Strength)**			Total 66.22					Total 0.02		
13	Total Losses										
13a	**Percentage Strength Lost**			0.27%					100.00%		
13b	Total Points Lost			27.47					151.74		
		Old SFS					Old SFS				
14	**Absolute Category Losses**	Tanks	Infantry	Total			Tanks	Infantry	Total		
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	16.48	10.99	27.47			0.00	151.74	151.74		
		Tanks	Infantry				Tanks	Infantry			
15	**Percentage Category Losses**	0.16%	21.98%				0.00%	100.00%			
15a	**Assets Lost by Category**	0	73				0	667			
15b	**Assets Remaining**	20	260				0	0			

Figure 3 Example Showing Defender's Infantry Losses Artificially Increasing

Now, the vulnerability of the defender's infantry should only be affected by the attacker's Anti-Infantry Strength Multipliers and the number of assets the attacker has, and not by the defender's Infantry Anti-Armour Strength Multiplier. Both before and after the change to the defender's Infantry Anti-Armour Strength Multiplier the attacker has less than half the anti-infantry capability. So why is there such a large (or any) change in the defender's infantry losses?

The answer has several parts - the Proportion of the Requirement is only used to modify the Armour and Infantry Strengths and aggregation is used to compute Total Final Strengths and single Force Ratio (for each side), and this single Force Ratio is used to compute total losses that are then disaggregated into losses of armour and infantry. This aggregation – disaggregation process is incapable of accurately reflecting the situation as described by the Proportion of the Requirements captured in Step 10b.

4. Solution to Improve Situational Force Scoring

The last part of the answer above also suggests a solution to the problem. That is, to use the Proportion of the Requirement from Step 10b, modified by the Shortage Divisor in Step 10d, to create a set of Anti-Strength Force Ratios. Here, the Shortage Divisor of one side is used not to improve (via a divisor) the enemy's Adjusted Strength for his assets, but is used to penalise (via a multiplier) ones own Proportion of the Requirement, resulting in an Anti-Strength Force Ratio.

Thus, Step 12 in the above process is replaced by the following. For the example calculations, the situation with the two changes made (to the defender's Infantry Anti-Armour Strength Multiplier and Shortage Divisor) will be used initially, before working back to the original data.

Step 12. The Proportion of the Requirement in Step 10b is multiplied by the Shortage Divisor in Step 10d to produce an Anti-Strength Force Ratio. Here, for the attacker the Anti-Armour Force Ratio is given by 9999*1.0 = 9999 and the Anti-Infantry Force Ratio is given by 0.45*0.66 = 0.30 (since the attacker had insufficient anti-infantry capability, his original Proportion of the Requirement is penalised by a factor of 0.66). For the defender the Anti-Armour Force Ratio is given by 0*0 = 0 and the Anti-Infantry Force Ratio is given by 2.0*1.0 = 2.0. This is the set of four Anti-Strength Force Ratios.

Since aggregation is avoided in this proposed scheme, Step 13 can now be avoided. Step 14 is also currently avoided as it has yet to be determined how the Participation Factors can be appropriately included. This is a limitation of the proposed scheme and remains an area for further research. Step 15 is now replaced by the following.

Step 15. The percentage losses of each asset type for each side is calculated using a single power law (in fact the same power law as for the original Situational Force

Scoring) but with the set of Anti-Strength Force Ratios. The power law used for each side is:

Percentage Strength Lost = MINIMUM[1,0.135*POWER(Enemy Anti-Strength Force Ratio,0.93)]

Note that the positive power of 0.93 is used here, since the Anti-Strength Force Ratio of the enemy is used in calculating own losses. Thus, for the attacker, the Percentage Armour Lost = MINIMUM[1,0.135*POWER(0.0,0.93)] = 0% and the Percentage Infantry Lost = MINIMUM[1,0.135*POWER(2.0,0.93)] = 25.72%, while for the defender the Percentage Armour Lost = MINIMUM[1,0.135*POWER(9999,0.93)] = 100% and the Percentage Infantry Lost = MINIMUM[1,0.135*POWER(0.3,0.93)] = 4.36%.

Steps 15a and b are unchanged. The spreadsheet for this example is given in Figure 4 below.

		ATTACKER					DEFENDER				
Step	**Description**	**Tanks**	**Infantry**	**Total**	**Anti-Tank**	**Anti-Infantry**	**Tanks**	**Infantry**	**Total**	**Anti-Tank**	**Anti Infantry**
1	**Number of Assets**	20	333				0	667			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		6.25					999.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.6				1	0.8
8b	Infantry				0.02	1				0	1
9	**Anti-Strength**				51.00	90.00				0.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				9999.00	0.45				0.00	2.00
10c	Shortage Intercept				0.17	0.38				0.00	0.38
10d	Shortage Divisor				1.00	0.66				0.00	1.00
11	**Final Strength**	9999.00	50.00	10049.00			0.00	151.74	151.74		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti Infantry
12	**Force Ratio (Strength or Anti-Strength)**			66.22	9999.00	0.30			0.02	0.00	2.00
13	Total Losses										
13a	**Percentage Strength Lost**			0.27%					100.00%		
13b	Total Points Lost			27.47					151.74		
		Old SFS			New SFS		Old SFS			New SFS	
		Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14	**Absolute Category Losses**										
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	16.48	10.99	27.47			0.00	151.74	151.74		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	0.16%	21.98%		0.00%	25.72%	0.00%	100.00%		100.00%	4.36%
15a	**Assets Lost by Category**	0	73		0	86	0	667		0	29
15b	**Assets Remaining**	20	260		20	248	0	0		0	638

Figure 4 Proposed Improvements to Situational Force Scoring - Compare with Figure 3

We see that the proposed changes better reflect the circumstances. The attacker, with only 0.45 of the required Anti-Infantry capability now only inflicts 4% attrition to the defender's infantry (compared with 100% from the original SFS). The attrition suffered by the attacker is similar in both approaches with exactly 0% armour losses and 26% of infantry losses (compared with 0.16% (i.e. not exactly zero) and 22% from the original SFS). Finally, note that although the proposed approach now suggests 100% attrition to the defender's armour (a result of the attacker's infinite Anti-Armour Force Ratio) the actual defender's armour losses will be the required zero (see Step 15a) since 100% of zero is zero.

Finally, we can compare the two approaches with the two changes (to the defender's Infantry Anti-Armour Strength Multiplier and Shortage Divisor) reverted, since they were primarily used to attempt to fix the problems with the original SFS. Figure 5 provides a comparison with the less harsh Shortage Intercept in Step 10c.

		ATTACKER					DEFENDER				
Step	Description	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry	Tanks	Infantry	Total	Anti-Tank	Anti-Infantry
1	**Number of Assets**	20	333				0	667			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		6.25					999.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.8				1	0.8
8b	Infantry				0.02	1				0	1
9	**Anti-Strength**				51.00	90.00				0.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				9999.00	0.45				0.00	2.00
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.66				0.29	1.00
11	**Final Strength**	172.41	50.00	222.41			0.00	151.74	151.74		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti-Infantry
12	**Force Ratio (Strength or Anti-Strength)**			1.47	9999.00	0.30			0.68	0.00	2.00
13	Total Losses										
13a	**Percentage Strength Lost**			9.46%					19.26%		
13b	Total Points Lost			21.04					29.23		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	12.62	8.42	21.04			0.00	29.23	29.23		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	7.32%	16.83%		0.00%	25.72%	0.00%	19.26%		100.00%	4.36%
15a	**Assets Lost by Category**	1	56		0	86	0	128		0	29
15b	**Assets Remaining**	19	277		20	248	0	538		0	638

Figure 5 Proposed Improvements to Situational Force Scoring - Compare with Figure 2

Recall that the problem in Figure 2 was that there were armour losses of 7% inflicted by the defender on the attacker (where no anti-armour capability existed). This is now remedied by the proposed approach (with 0% armour losses). Also note that the attacker's infantry losses increase from 17% to 26% under the proposed approach. The reason for this is as a result of the disaggregation of SFS, whereby the process is unable to partition the losses sufficiently. The result is that the attacker's armour 'shares' in losses that are in fact 'due' to its infantry (note that adding the attacker's armour and infantry percent losses yields 24%, which is closer to the corresponding sum under the proposed approach).

		ATTACKER					DEFENDER				
Step	**Description**	**Tanks**	**Infantry**	**Total**	**Anti-Tank**	**Anti-Infantry**	**Tanks**	**Infantry**	**Total**	**Anti Tank**	**Anti Infantry**
1	**Number of Assets**	**20**	**333**				**0**	**667**			
2	Asset Scores	2.6	0.15				2.5	0.15			
3	**Raw Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1	1				1	1			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		**6.25**					**999.00**			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	50.00	50.00	100.00			0.00	100.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Tank				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				51.00	90.00				2.00	100.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				**9999.00**	**0.45**				**0.08**	**2.00**
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.66				0.35	1.00
11	**Final Strength**	144.18	50.00	194.18			0.00	151.74	151.74		
12	**Force Ratio (Strength or Anti-Strength)**			**1.28**	**9999.00**	**0.30**			**0.78**	**0.03**	**2.00**
13	Total Losses										
13a	**Percentage Strength Lost**			10.73%					16.98%		
13b	Total Points Lost			20.84					25.77		

		ATTACKER Old SFS			ATTACKER New SFS		DEFENDER Old SFS			DEFENDER New SFS	
Step	**Description**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**
14	**Absolute Category Losses**										
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	60.00%	40.00%				0.00%	100.00%			
14c	Category Points Lost	12.51	8.34	20.84			0.00	25.77	25.77		
15	**Percentage Category Losses**	**8.67%**	**16.67%**		**0.48%**	**25.72%**	**0.00%**	**16.98%**		**100.00%**	**4.36%**
15a	**Assets Lost by Category**	2	56		0	86	0	113		0	29
15b	**Assets Remaining**	18	278		20	248	0	553		0	638

Figure 6 Proposed Improvements to Situational Force Scoring - Compare with Figure 1

The other point to note is the difference between predicted infantry losses to the defender. The original SFS yields 19% while the proposed approach only suggests 4%. Here, there is no right or wrong answer and calibration of the models would have to be

performed before judgements could be passed. However, it is true that the reason for the higher percentage is because an aggregated Force Ratio is used (the final Armour Strength and the Final Infantry Strength for each side). Thus the inflated attacker's armour strength is combined with his infantry strength and this is pitted against the defender's inflated infantry strength to yield the Force Ratio of 1.47 for the attacker.

Now a Force Ratio greater than one is used to signify a position of advantage, however we have seen that the attacker has less than half the required anti-infantry capability. Therefore a Force Ratio of 1.47 in this situation appears to be at odds with the data, and it is suggested that the Anti-Infantry Force Ratio of 0.3 suggested by the proposed approach is more in line with expectations.

Finally, we revert to the original data (whereby the defending infantry have a slight anti-armour capability). Figure 6 provides the results. Here, we see that the attacker correctly suffers only very slight attrition to his armour assets (approximately half a percent) compared to the 8.67% that the original SFS suggests. The other attrition results are similar to Figure 5.

5. Application – Optimising Combined Arms

The aim of this paper is twofold. First, to recommend a slight change to the process of Situational Force Scoring that, in the author's opinion, appears more logical and in line with expectations generated from the data. The other aim is to illustrate one application of such a model. One of the obvious advantages of a lower-resolution simulation like SFS is the ability to perform exploratory analysis. This is particularly important for analysis of complex systems such as a defence force. As discussed in the introduction having robust combined arms units within Army is critical to achieving the best from a limited resource, and in having those units 'punch above their weight'.

In this section, we illustrate an application of exploratory analysis using Situational Force Scoring, both with the original and proposed approach, to determine appropriately balanced combined arms units under varying environmental and enemy conditions.

In this experiment, we will consider two environmental and three enemy conditions. The environment will be characterised by the type of terrain, with the two levels corresponding to open terrain and closed terrain. The enemy will be characterised by the mix of armour and infantry forces, with the three levels corresponding to a pure armour force, a mix of armour and infantry forces, and a pure infantry force. The enemy is taken to be the defender.

The constraint imposed on both sides is that each are 'given' 100 Raw Score points from which to partition into armour and infantry assets. For the enemy, the three levels

described above decide this partitioning. For the attacker, the optimisation problem is to determine the appropriate partitioning so as to optimise some quantitative measure.

For the quantitative measure there are various options available, including minimising attacker attrition, maximizing enemy attrition, or maximizing a loss exchange ratio (LER). Each has their advantages and disadvantages, and in practice should be chosen to adequately represent the actual problem at hand. For this illustration, we will be using a form of LER.

Since both sides are (potentially) a heterogeneous mix of units (armour and infantry) some form of uniform measure must be used when combining the two sources of attrition into the single LER. This measure is the Asset Scores. The Assets Lost by each side is converted into Asset Score Points lost and added to produce the Total Asset Score Points lost. The LER is then the ratio of the defender's Total Asset Score Points lost to the attacker's Total Asset Score Points lost.

To aid the illustration and discussion of the results, the optimisation will be performed by visually inspecting the three-dimensional plot where the horizontal axes are the numbers of armour and infantry assets the attacker has and the vertical axis is the resulting LER as defined above. These plots will be provided in pairs, with the original SFS on the left and the proposed approach on the right, to aid in comparison.

5.1 Open Terrain, Pure Infantry Defender

This corresponds to the defender having 666 infantry assets only (approximately two infantry battalions). Figure 7 displays the results in these circumstances. There are several features of this figure that require discussion. The original SFS predicts an optimum attacking force of 33 armour assets (a regiment of tanks) and 113 infantry assets (an infantry company), which yields a LER of 4.69. The proposed approach predicts an optimum attacking force of 40 armour assets and no infantry assets, which yields a LER of 3.11.

While both approaches predict an armour heavy attacking force they vary by the degree of heaviness, with the proposed approach suggesting a pure armour force. Both approaches also vary in the predicted LER, with the proposed approach suggesting a smaller LER. To investigate the reasons for these variations, we need to produce the lower level data that generated these results. This is provided in Figures 8 and 9.

Figure 8 below indicates that the original SFS includes only enough infantry forces to avoid being penalised in Step 6. The resulting overall Force Ratio of 2.43 then inflicts relatively heavy attrition to the enemy's infantry while keeping relatively low losses to the attacker's armour and infantry. However, Figure 8 also shows that this attacking force has only half the anti-infantry capability while the enemy has almost six times the anti-infantry capability required, which as suggested before appear at odds with the resulting attrition. Figure 8 shows that under the proposed approach this solution in

fact results in massive infantry attrition to the attacker (70%) while only inflicting minor attrition to the defender's infantry (5%), and thus hardly the optimal force mix.

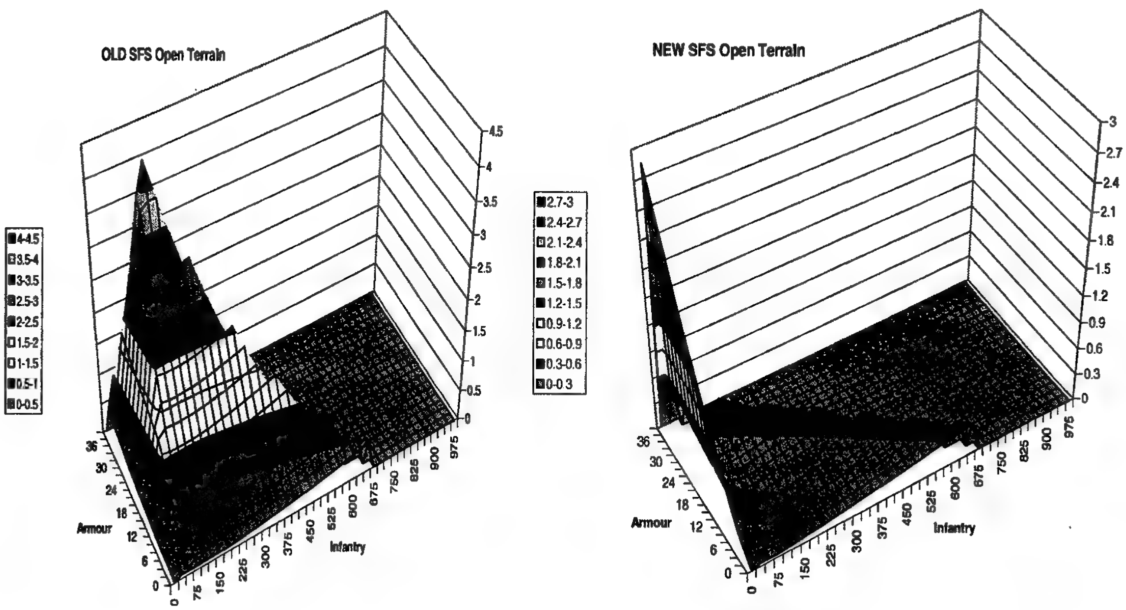

Figure 7 Open Terrain, Pure Infantry Defender - Variation of LER with Attackers Force Mix

		ATTACKER					DEFENDER				
Step	**Description**	**Armour**	**Infantry**	**Total**	**Anti-Armour**	**Anti-Infantry**	**Armour**	**Infantry**	**Total**	**Anti-Armour**	**Anti-Infantry**
1	**Number of Assets**	**33**	**113**				**0**	**667**			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	82.50	16.95	99.45			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1.15	0.9				1.1	0.9			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	94.88	15.26	110.13			0.00	90.00	90.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		**1.00**					**999.00**			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	94.88	15.26	110.13			0.00	90.00	90.00		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				95.18	91.16				1.80	90.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				**9999.00**	**0.51**				**0.04**	**5.90**
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.69				0.32	1.00
11	**Final Strength**	299.35	15.26	314.60			0.00	129.69	129.69		
				Total	**Anti-Tank**	**Anti-Infantry**			**Total**	**Anti-Tank**	**Anti-Infantry**
12	**Force Ratio (Strength or Anti-Strength)**			**2.43**	**9999.00**	**0.35**			**0.41**	**0.01**	**5.90**
13	Total Losses										
13a	**Percentage Strength Lost**			5.92%					30.78%		
13b	Total Points Lost			18.63					39.92		
		Old SFS			**New SFS**		**Old SFS**			**New SFS**	
14	**Absolute Category Losses**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	90.32%	9.68%				0.00%	100.00%			
14c	Category Points Lost	16.82	1.80	18.63			0.00	39.92	39.92		
		Tanks	**Infantry**		**Tanks**	**Infantry**	**Tanks**	**Infantry**		**Tanks**	**Infantry**
15	**Percentage Category Losses**	**5.62%**	**11.82%**		**0.22%**	**70.34%**	**0.00%**	**30.78%**		**100.00%**	**5.10%**
15a	**Assets Lost by Category**	2	13		0	79	0	205		0	34
15b	**Assets Remaining**	31	100		33	34	0	461		0	633

Figure 8 Open Terrain, Pure Infantry Defender –Original SFS Optimal Results

		ATTACKER					DEFENDER				
Step	Description	Armour	Infantry	Total	Anti-Armour	Anti-Infantry	Armour	Infantry	Total	Anti-Armour	Anti-Infantry
1	**Number of Assets**	40	0				0	667			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	100.00	0.00	100.00			0.00	100.00	100.00		
4	Situational Multipliers										
4a	Terrain	1.15	0.9				1.1	0.9			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	115.00	0.00	115.00			0.00	90.00	90.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		0.00					999.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		0.38					1.00			
7	**Adjusted Strength**	43.70	0.00	43.70			0.00	90.00	90.00		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.6
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				43.70	34.96				1.80	90.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				9999.00	0.19				0.08	9999.00
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	0.50				0.35	1.00
11	**Final Strength**	125.40	0.00	125.40			0.00	179.85	179.85		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti-Infantry
12	**Force Ratio (Strength or Anti-Strength)**			0.70	9999.00	0.10			1.43	0.03	9999.00
13	Total Losses										
13a	**Percentage Strength Lost**			18.88%					9.65%		
13b	Total Points Lost			23.67					17.36		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	100.00%	0.00%				0.00%	100.00%			
14c	Category Points Lost	23.67	0.00	23.67			0.00	17.36	17.36		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	18.88%	0.00%		0.50%	100.00%	0.00%	9.65%		100.00%	1.54%
15a	**Assets Lost by Category**	8	0		0	0	0	64		0	10
15b	**Assets Remaining**	32	0		40	0	0	602		0	656

Figure 9 Open Terrain, Pure Infantry Defender –Proposed SFS Optimal Results

Figure 9 above indicates that the proposed approach views the addition of infantry as merely providing additional targets for the infantry forces of the enemy, and is willing to accept the penalty of insufficient infantry support to its armour as payment for boosting its highly invulnerable armour force. Interestingly, with this solution both sides are ill-equipped to attack the other, with the attacker having less than one-fifth the anti-infantry capability required and the defender having less than one-thirtieth the anti-armour capability required. Consequently, either side suffers very little attrition.

This last point illustrates a potential problem with using a LER as the measure of effectiveness. The problem is that it can be a very sensitive measure if the numerator and denominator are small numbers (as is the case in the above situation) – i.e. low attrition situations. This explains the sharpness in the peak of Figure 9.

5.2 Open Terrain, Combined Arms Defender

This corresponds to the defender having 20 armour (approximately two squadrons) and 333 infantry assets only (approximately one infantry battalion). Figure 10 displays the results in these circumstances. The original SFS predicts an optimum attacking force of 33 armour assets (a regiment of tanks) and 113 infantry assets (an infantry company), which yields a LER of 1.08. This is the same attacking force mix solution as for the pure infantry enemy, but has a substantially lower LER. The proposed approach interestingly appears to predict two alternative optimum attacking forces of either 33 armour assets (a regiment of tanks) and 113 infantry assets (an infantry company) (the

same solution as the original SFS), or one consisting of only 667 infantry assets (two infantry battalions), both of which yields a LER of 0.50. To investigate the reasons for the two alternative force mixes, we need to produce the lower level data that generated these results. This is provided in Figures 11 and 12.

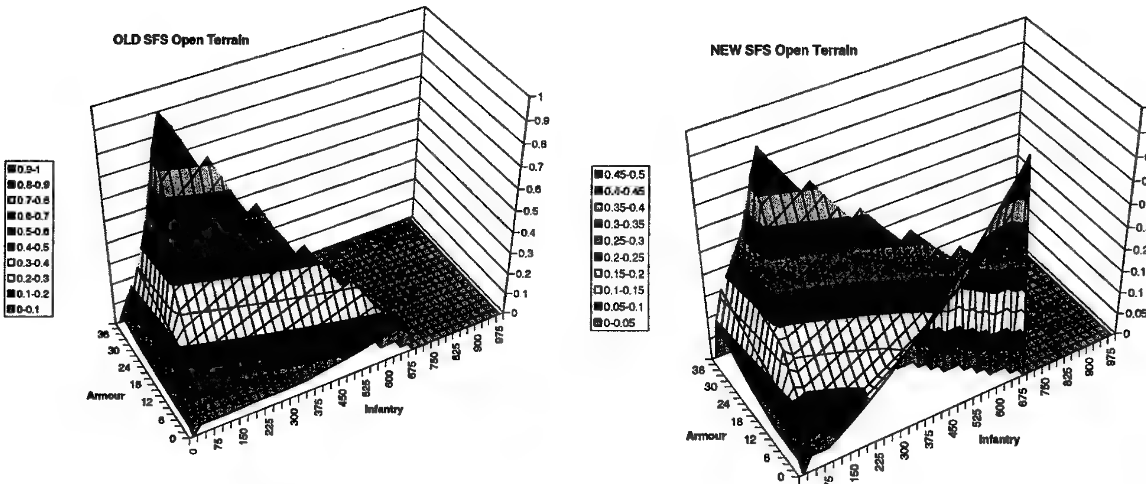

Figure 10 Open Terrain, Combined Arms Defender - Variation of LER with Attackers Force Mix

		ATTACKER					DEFENDER				
Step	Description	Armour	Infantry	Total	Anti-Armour	Anti-Infantry	Armour	Infantry	Total	Anti-Armour	Anti-Infantry
1	**Number of Assets**	33	113				20	333			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	83.03	16.97	100.00			50.00	50.00	100.00		
4	Situational Multipliers										
4a	Terrain	1.15	0.9				1.1	0.9			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	95.48	15.28	110.76			55.00	45.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		1.00					5.11			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	95.48	15.28	110.76			55.00	45.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				95.78	91.66				55.90	89.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				0.87	1.02				1.17	5.83
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				0.89	1.00				1.00	1.00
11	**Final Strength**	95.40	15.20	110.76			61.61	45.00	106.61		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti-Infantry
12	**Force Ratio (Strength or Anti-Strength)**			1.04	0.78	1.02			0.96	1.17	5.83
13	Total Losses										
13a	**Percentage Strength Lost**			13.03%					13.99%		
13b	Total Points Lost			14.43					14.91		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	90.36%	9.64%				59.46%	40.54%			
14c	Category Points Lost	13.04	1.39	14.43			8.87	6.05	14.91		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	13.66%	9.10%		15.63%	69.52%	14.39%	13.43%		10.68%	13.73%
15a	**Assets Lost by Category**	5	10		5	79	3	45		2	46
15b	**Assets Remaining**	29	103		28	34	17	289		18	288

Figure 11 Open Terrain, Combined Arms Defender –Proposed SFS Optimal Results for First Solution

Step	Description	ATTACKER Armour	ATTACKER Infantry	ATTACKER Total	ATTACKER Anti-Armour	ATTACKER Anti-Infantry	DEFENDER Armour	DEFENDER Infantry	DEFENDER Total	DEFENDER Anti-Armour	DEFENDER Anti-Infantry
1	**Number of Assets**	**0**	**667**				**20**	**333**			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	0.00	100.00	100.00			50.00	50.00	100.00		
4	Situational Multipliers										
4a	Terrain	1.15	0.9				1.1	0.9			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	0.00	90.00	90.00			55.00	45.00	100.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	**Proportion of Requirement**		**999.00**					**5.11**			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	0.00	90.00	90.00			55.00	45.00	100.00		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.6
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				1.80	90.00				55.90	89.00
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	**Proportion of Requirement**				**0.02**	**1.00**				**9999.00**	**0.99**
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				0.18	1.00				1.00	0.99
11	**Final Strength**	0.00	90.67	90.67			299.59	45.00	344.59		
				Total	Anti-Tank	Anti-Infantry			Total	Anti Tank	Anti Infantry
12	**Force Ratio (Strength or Anti-Strength)**			**0.26**	**0.00**	**1.00**			**3.80**	**9999.00**	**0.98**
13	Total Losses										
13a	**Percentage Strength Lost**			46.75%					3.90%		
13b	Total Points Lost			42.37					13.43		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	0.00%	100.00%				59.46%	40.54%			
14c	Category Points Lost	0.00	42.37	42.37			7.99	5.45	13.43		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	**0.00%**	**46.75%**		**100.00%**	**13.27%**	**2.67%**	**12.10%**		**0.06%**	**13.50%**
15a	**Assets Lost by Category**	0	312		0	88	1	40		0	45
15b	**Assets Remaining**	0	355		0	578	19	293		20	288

Figure 12 Open Terrain, Combined Arms Defender –Proposed SFS Optimal Results for Second Solution

Figure 11 first shows that under the original SFS, both sides fare approximately equal with comparable losses to armour and infantry, with a resulting LER of 1.08. However, under the proposed approach the attacking infantry suffer higher relative attrition, with 70% losses compared with only 14% to the defender, and the resulting LER is 0.50.

Figure 12 then shows the results for the alternative, infantry only, solution under the proposed approach. Here the percentage losses for the attacker are lower, with only 13% of the infantry forces lost. However, the attacker loses virtually any ability to inflict attrition to the enemy's armour assets as a result. The net result is an identical LER as to the combined arms solution in Figure 11 of 0.50.

This also illustrates another issue with interpreting the results. While the latter situation in Figure 11 appears decidedly poor for the attacker in terms of losses to infantry, it must be noted that the attacker has only one third the infantry forces than the defender, so while 70% may appear very high, the actual number of infantry forces lost are 79 of the attacker and 46 of the defender. Similarly, the reduction of the attacker's infantry losses from 70% to 13% in Figure 12 actually results in more losses to the attacker's infantry (88 compared to 79).

5.3 Open Terrain, Pure Armour Defender

This corresponds to the defender having 40 armour (approximately four squadrons) and no infantry assets. Figure 13 displays the results in these circumstances. Here, both the original SFS and proposed approach predict an optimum attacking force of 33 armour assets (a regiment of tanks) and 113 infantry assets (an infantry company). The resulting LERs differ, however, with the original SFS yielding a LER of 7.20 and the proposed approach yielding a LER of 1.11. Figure 14 provides the lower level data for both solutions.

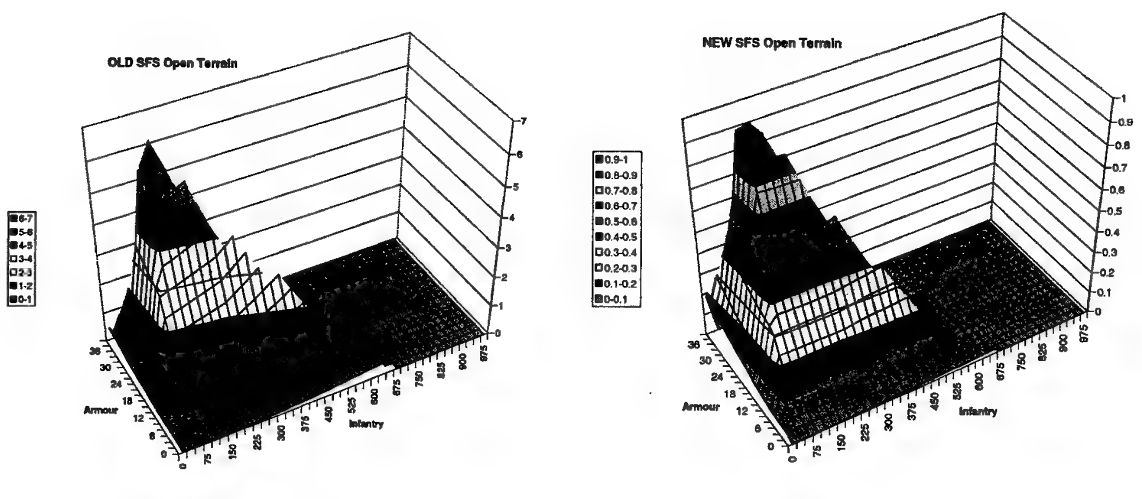

Figure 13 Open Terrain, Pure Armour Defender - Variation of LER with Attackers Force Mix

Here we see the original SFS predicting low losses to the attacker (around 5% losses to both armour and infantry) and high armour losses to the enemy (36%), while the proposed approach is quite different. There the attacker suffers higher infantry losses (28% due to the enemy having more than twice the required anti-infantry capability) while inflicting fewer armour losses to the enemy (15% due to the attacker having only slightly more than the required anti-armour capability). These observations explain the discrepancy in the resultant LERs.

		ATTACKER					DEFENDER				
Step	Description	Armour	Infantry	Total	Anti-Armour	Anti-Infantry	Armour	Infantry	Total	Anti-Armour	Anti-Infantry
1	Number of Assets	33	113				40	0			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	Raw Strength	82.50	17.00	99.50			100.00	0.00	100.00		
4	Situational Multipliers										
4a	Terrain	1.15	0.9				1.1	0.9			
4b	Battle Type	1	1				1	1			
5	Situational Strength	94.88	15.30	110.17			110.00	0.00	110.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		0.16					0.16			
6b	Proportion of Requirement		1.01					0.00			
6c	Shortage Intercept		0.38					0.38			
6d	Shortage Multiplier		1.00					0.36			
7	Adjusted Strength	94.88	15.30	110.17			41.80	0.00	41.80		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	Anti-Strength				95.18	91.20				41.80	33.44
10	Shortages in Anti-Strengths										
10a	Required Multiple				2	2				0.5	1
10b	Proportion of Requirement				1.14	9999.00				0.88	2.19
10c	Shortage Intercept				0.17	0.38				0.29	0.38
10d	Shortage Divisor				1.00	1.00				0.92	1.00
11	Final Strength	103.62	15.30	118.92			41.80	0.00	41.80		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti-Infantry
12	Force Ratio (Strength or Anti-Strength)			2.84	1.14	9999.00			0.35	0.81	2.19
13	Total Losses										
13a	Percentage Strength Lost			5.11%					35.70%		
13b	Total Points Lost			6.07					14.92		
		Old SFS			New SFS		Old SFS			New SFS	
14	Absolute Category Losses	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	90.29%	9.71%				100.00%	0.00%			
14c	Category Points Lost	5.48	0.59	6.07			14.92	0.00	14.92		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	Percentage Category Losses	5.29%	3.85%		11.06%	27.94%	35.70%	0.00%		15.23%	100.00%
15a	Assets Lost by Category	2	4		4	32	14	0		6	0
15b	Assets Remaining	31	109		29	82	26	0		34	0

Figure 14 Open Terrain, Pure Armour Defender –Original and Proposed SFS Optimal Results

5.4 Closed Terrain, Pure Infantry Defender

The results are expected to be different between open terrain and closed terrain for a variety of reasons. Closed terrain enhances the effectiveness of infantry and armour requires more infantry support to reduce its vulnerability. The attacker also requires considerably more anti-infantry capability when fighting in closed terrain. Thus, the parameters in Steps 4a, 6a, 6c, 10a and 10c are different depending on the type of terrain.

The first condition corresponds to the defender having 666 infantry assets only (approximately two infantry battalions). Figure 15 displays the results in these circumstances. Here, both the original SFS and proposed approach predict an optimum attacking force of 667 infantry assets (two infantry battalions). Both produce similar LERs of 0.37 (original SFS) and 0.32 (proposed approach). Figure 16 provides the lower level data for both solutions.

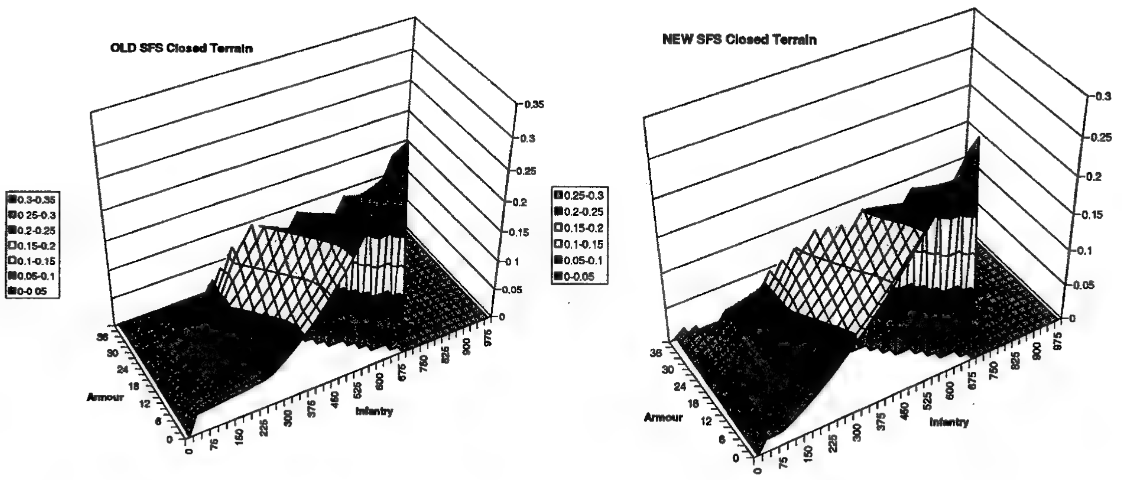

Figure 15 Closed Terrain, Pure Infantry Defender - Variation of LER with Attackers Force Mix

		ATTACKER					DEFENDER				
Step	**Description**	**Armour**	**Infantry**	**Total**	**Anti-Armour**	**Anti-Infantry**	**Armour**	**Infantry**	**Total**	**Anti-Armour**	**Anti-Infantry**
1	**Number of Assets**	**0**	**666**				**0**	**666**			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	0.00	99.90	99.90			0.00	99.90	99.90		
4	Situational Multipliers										
4a	Terrain	0.8	1.6				0.8	1.6			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	0.00	159.84	159.84			0.00	159.84	159.84		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		1.6					1.2			
6b	**Proportion of Requirement**		**999.00**					**999.00**			
6c	Shortage Intercept		0.17					0.17			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	0.00	159.84	159.84			0.00	159.84	159.84		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.6
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				3.20	159.84				3.20	159.84
10	Shortages in Anti-Strengths										
10a	Required Multiple				1	2				0.3	1
10b	**Proportion of Requirement**				**9999.00**	**0.50**				**9999.00**	**1.00**
10c	Shortage Intercept				0.44	0.17				0.44	0.17
10d	Shortage Divisor				1.00	0.59				1.00	1.00
11	**Final Strength**	0.00	159.84	159.84			0.00	273.23	273.23		
				Total	**Anti-Tank**	**Anti-Infantry**			**Total**	**Anti-Tank**	**Anti-Infantry**
12	**Force Ratio (Strength or Anti-Strength)**			**0.59**	**9999.00**	**0.29**			**1.71**	**9999.00**	**1.00**
13	Total Losses										
13a	**Percentage Strength Lost**			22.23%					8.20%		
13b	Total Points Lost			35.53					22.40		
		Old SFS			**New SFS**		**Old SFS**			**New SFS**	
14	**Absolute Category Losses**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	0.00%	100.00%				0.00%	100.00%			
14c	Category Points Lost	0.00	35.53	35.53			0.00	22.40	22.40		
		Tanks	**Infantry**		**Tanks**	**Infantry**	**Tanks**	**Infantry**		**Tanks**	**Infantry**
15	**Percentage Category Losses**	**0.00%**	**22.23%**		**100.00%**	**13.50%**	**0.00%**	**8.20%**		**100.00%**	**4.30%**
15a	**Assets Lost by Category**	0	148		0	90	0	55		0	29
15b	**Assets Remaining**	0	518		0	576	0	611		0	637

Figure 16 Closed Terrain, Pure Infantry Defender –Original and Proposed SFS Optimal Results

5.5 Closed Terrain, Combined Arms Defender

This corresponds to the defender having 20 armour (approximately two squadrons) and 333 infantry assets only (approximately one infantry battalion). Figure 17 displays the results in these circumstances.

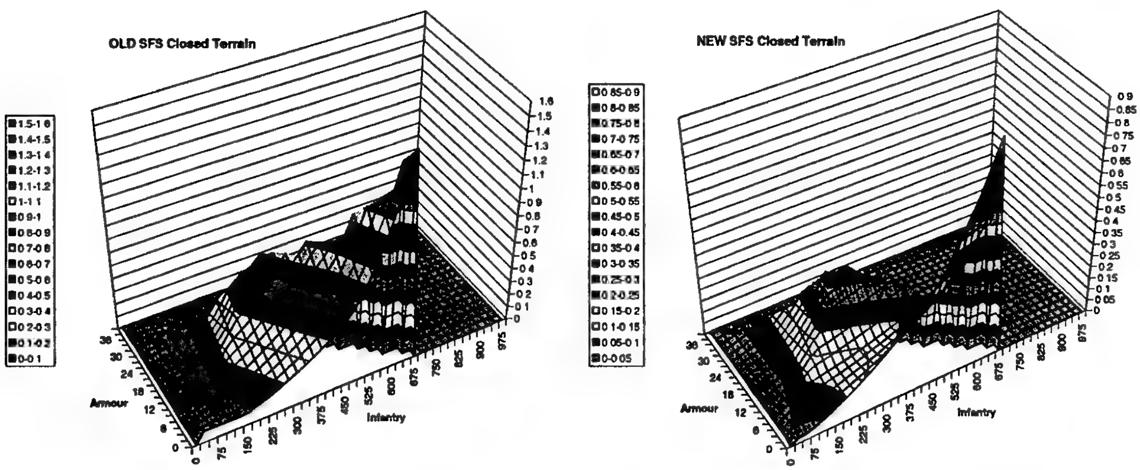

Figure 17 Closed Terrain, Combined Arms Defender - Variation of LER with Attackers Force Mix

		ATTACKER					DEFENDER				
Step	Description	Armour	Infantry	Total	Anti-Armour	Anti-Infantry	Armour	Infantry	Total	Anti-Armour	Anti-Infantry
1	**Number of Assets**	0	666				20	333			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	0.00	99.90	99.90			50.00	49.95	99.95		
4	Situational Multipliers										
4a	Terrain	0.8	1.6				0.8	1.6			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	0.00	159.84	159.84			40.00	79.92	119.92		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		1.6					1.2			
6b	**Proportion of Requirement**		999.00					1.67			
6c	Shortage Intercept		0.17					0.17			
6d	Shortage Multiplier		1.00					1.00			
7	**Adjusted Strength**	0.00	159.84	159.84			40.00	79.92	119.92		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				3.20	159.84				41.60	111.92
10	Shortages in Anti-Strengths										
10a	Required Multiple				1	2				0.3	1
10b	**Proportion of Requirement**				0.08	1.00				9999.00	0.70
10c	Shortage Intercept				0.44	0.17				0.44	0.17
10d	Shortage Divisor				0.48	1.00				1.00	0.75
11	**Final Strength**	0.00	212.79	212.79			82.52	79.92	162.44		
				Total	Anti-Tank	Anti-Infantry			Total	Anti Tank	Anti Infantry
12	**Force Ratio (Strength or Anti-Strength)**			1.31	0.04	1.00			0.76	9999.00	0.53
13	Total Losses										
13a	**Percentage Strength Lost**			10.50%					17.35%		
13b	Total Points Lost			22.35					28.19		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	0.00%	100.00%				37.52%	62.48%			
14c	Category Points Lost	0.00	22.35	22.35			10.58	17.61	28.19		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	0.00%	10.50%		100.00%	7.43%	12.82%	22.04%		0.66%	13.50%
15a	**Assets Lost by Category**	0	70		0	49	3	73		0	45
15b	**Assets Remaining**	0	596		0	617	17	260		20	288

Figure 18 Closed Terrain, Combined Arms Defender –Original and Proposed SFS Optimal Results

Again, both the original SFS and proposed approach predict an optimum attacking force of 667 infantry assets (two infantry battalions). However, they produce dissimilar LERs of 1.66 (original SFS) and 0.95 (proposed approach). Figure 18 provides the lower level data for both solutions.

5.6 Closed Terrain, Pure Armour Defender

This corresponds to the defender having 40 armour (approximately four squadrons) and no infantry assets. Figure 19 displays the results in these circumstances. Again, both the original SFS and proposed approach predict an optimum attacking force of 667 infantry assets (two infantry battalions). However, they produce vastly dissimilar LERs of 173.48 (original SFS) and 7.50 (proposed approach). Figure 20 provides the lower level data for both solutions.

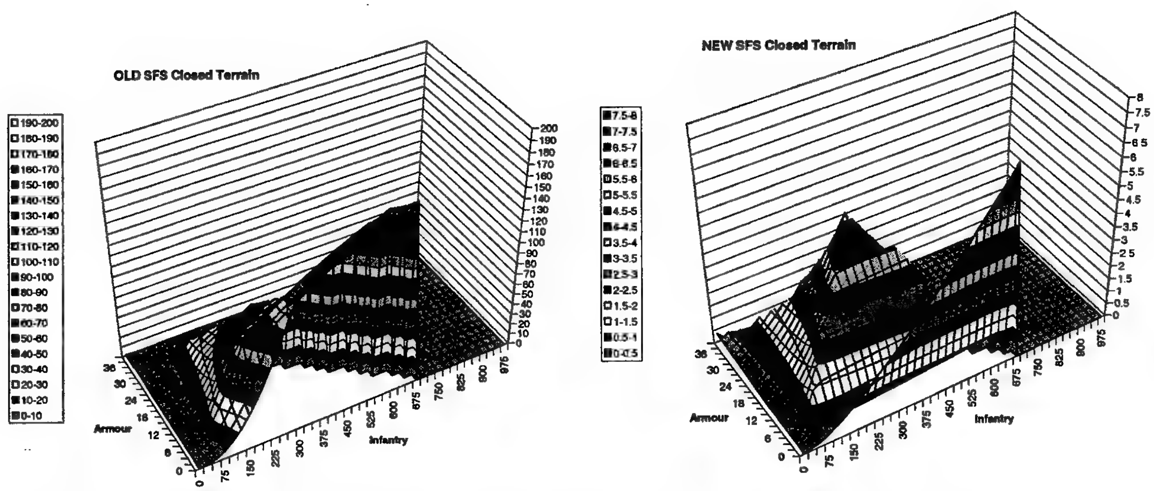

Figure 19 Closed Terrain, Pure Armour Defender - Variation of LER with Attackers Force Mix

The reason for the large discrepancy in the LER is due to the different processes used in the two versions of SFS. The original SFS yields a massive (aggregate) Force Ratio and therefore total annihilation of the enemy (and with the LER being a ratio leads to a very large value). The proposed approach yields a sort of standoff, with the enemy's armour being very ineffectual in the closed terrain, and the attacker's infantry not having the required anti-armour capability to inflict significant attrition. However, even with such minimal attrition the situation still favours the attacker (with the LER being greater than one).

Step	Description	ATTACKER Armour	Infantry	Total	Anti-Armour	Anti-Infantry	DEFENDER Armour	Infantry	Total	Anti-Armour	Anti-Infantry
1	**Number of Assets**	0	666				40	0			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	0.00	99.90	99.90			100.00	0.00	100.00		
4	Situational Multipliers										
4a	Terrain	0.8	1.6				0.8	1.6			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	0.00	159.84	159.84			80.00	0.00	80.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		1.6					1.2			
6b	**Proportion of Requirement**		999.00					0.00			
6c	Shortage Intercept		0.17					0.17			
6d	Shortage Multiplier		1.00					0.17			
7	**Adjusted Strength**	0.00	159.84	159.84			13.60	0.00	13.60		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				3.20	159.84				13.60	10.88
10	Shortages in Anti-Strengths										
10a	Required Multiple				1	2				0.3	1
10b	**Proportion of Requirement**				0.24	9999.00				9999.00	0.07
10c	Shortage Intercept				0.44	0.17				0.44	0.17
10d	Shortage Divisor				0.57	1.00				1.00	0.23
11	**Final Strength**	0.00	705.71	705.71			23.79	0.00	23.79		
				Total	Anti-Tank	Anti-Infantry			Total	Anti-Tank	Anti Infantry
12	**Force Ratio (Strength or Anti-Strength)**			29.66	0.13	9999.00			0.03	9999.00	0.02
13	Total Losses										
13a	**Percentage Strength Lost**			0.58%					100.00%		
13b	Total Points Lost			4.07					23.79		
		Old SFS			New SFS		Old SFS			New SFS	
14	**Absolute Category Losses**	Tanks	Infantry	Total	Tanks	Infantry	Tanks	Infantry	Total	Tanks	Infantry
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	0.00%	100.00%				100.00%	0.00%			
14c	Category Points Lost	0.00	4.07	4.07			23.79	0.00	23.79		
		Tanks	Infantry		Tanks	Infantry	Tanks	Infantry		Tanks	Infantry
15	**Percentage Category Losses**	0.00%	0.58%		100.00%	0.28%	100.00%	0.00%		2.09%	100.00%
15a	**Assets Lost by Category**	0	4		0	2	40	0		1	0
15b	**Assets Remaining**	0	662		0	664	0	0		39	0

Figure 20 Closed Terrain, Pure Armour Defender –Original and Proposed SFS Optimal Results

Interestingly, the proposed approach also seems to suggest an alternative solution, indicated by the second peak in Figure 19. While not technically optimal (it does have a smaller LER than the pure infantry solution above), because of the above-mentioned issues with using a LER, it deserves further attention. Figure 21 provides the lower level data for this solution.

The alternative solution has a combined arms attacking force of 22 armour assets (approximately two tank squadrons) and 296 infantry assets (approximately one infantry battalion). This solution yields LERs of 62.84 (original SFS) and 5.24 (proposed approach). The situation with the original SFS is virtually unchanged – the enemy is completely annihilated and the attacker suffers very few casualties.

However, under the proposed approach the situation is considerably different. First, there is more attrition to both sides, with the addition of the attacking armour. The attacker suffers 14% attrition to his armour but is able to inflict over 40% attrition to the enemy's armour. Thus, with an alternative measure of effectiveness, for example the attrition inflicted upon the enemy, this would be a preferred solution to the pure infantry solution above.

Step	Description	ATTACKER Armour	ATTACKER Infantry	ATTACKER Total	ATTACKER Anti-Armour	ATTACKER Anti-Infantry	DEFENDER Armour	DEFENDER Infantry	DEFENDER Total	DEFENDER Anti-Armour	DEFENDER Anti-Infantry
1	**Number of Assets**	22	296				40	0			
2	Asset Scores	2.5	0.15				2.5	0.15			
3	**Raw Strength**	55.56	44.44	100.00			100.00	0.00	100.00		
4	Situational Multipliers										
4a	Terrain	0.8	1.6				0.8	1.6			
4b	Battle Type	1	1				1	1			
5	**Situational Strength**	44.44	71.11	115.56			80.00	0.00	80.00		
6	Shortage in Infantry Support to Armour										
6a	Required Multiple		1.6					1.2			
6b	**Proportion of Requirement**		1.00					0.00			
6c	Shortage Intercept		0.17					0.17			
6d	Shortage Multiplier		1.00					0.17			
7	**Adjusted Strength**	44.44	71.11	115.56			13.60	0.00	13.60		
8	Situational Anti-Strength Multipliers										
8a	Armour				1	0.8				1	0.8
8b	Infantry				0.02	1				0.02	1
9	**Anti-Strength**				45.87	106.67				13.60	10.88
10	Shortages in Anti-Strengths										
10a	Required Multiple				1	2				0.3	1
10b	**Proportion of Requirement**				3.37	9999.00				1.02	0.15
10c	Shortage Intercept				0.44	0.17				0.44	0.17
10d	Shortage Divisor				1.00	1.00				1.00	0.30
11	**Final Strength**	44.44	239.44	283.88			13.60	0.00	13.60		
				Total	**Anti-Tank**	**Anti-Infantry**			**Total**	**Anti-Tank**	**Anti-Infantry**
12	**Force Ratio (Strength or Anti-Strength)**			20.87	3.37	9999.00			0.05	1.02	0.05
13	Total Losses										
13a	**Percentage Strength Lost**			0.80%					100.00%		
13b	Total Points Lost			2.27					13.60		
		Old SFS			**New SFS**		**Old SFS**			**New SFS**	
14	**Absolute Category Losses**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**	**Tanks**	**Infantry**	**Total**	**Tanks**	**Infantry**
14a	Participation Factor	1.5	1				1.2	1			
14b	Relative Category Losses	48.39%	51.61%				100.00%	0.00%			
14c	Category Points Lost	1.10	1.17	2.27			13.60	0.00	13.60		
		Tanks	**Infantry**		**Tanks**	**Infantry**	**Tanks**	**Infantry**		**Tanks**	**Infantry**
15	**Percentage Category Losses**	2.47%	0.49%		13.75%	0.76%	100.00%	0.00%		41.82%	100.00%
15a	**Assets Lost by Category**	1	1		3	2	40	0		17	0
15b	**Assets Remaining**	22	295		19	294	0	0		23	0

Figure 21 Closed Terrain, Pure Armour Defender – Original and Proposed SFS Alternative Solution

5.7 Summary of Experiment

We have seen above that the proposed changes to SFS have not in all cases radically altered the results. However, we have also seen that there are some circumstances where the aggregation-disaggregation process of the original SFS appears to have difficulty in producing component attrition to both sides to suitably reflect the balances and imbalances between lethality and vulnerability and armour and infantry.

The experiment investigated two terrain types and three enemy force mixes, ranging from open to closed terrain and purely infantry to purely armour. The resulting optimal attacking force, as suggested by each of the two SFS approaches, for each situation is summarised in Table 1 below. The numbers in parenthesis refer to the number of armour and infantry assets for the attacker and the resulting LER. Where multiple solutions are suggested by the proposed approach these are listed together.

Table 1Optimal Attacking Force as a Function of Terrain and Enemy Force Mix

		Enemy Force Mix		
Terrain	**Method**	**Infantry**	**Combined Arms**	**Armour**
Open	**Original**	(33,113,4.69)	(33,113,1.08)	(33,113,7.20)
	Proposed	(40,0,3.11)	(33,113,0.5) (0,667,0.5)	(33,113,1.11)
Closed	**Original**	(0,667,0.37)	(0,667,1.66)	(0,667,173.48)
	Proposed	(0,667,0.32)	(0,667,0.95)	(0,667,7.50) (22,296,5.24)

From this table we clearly see the benefits of armour in open terrain and infantry in closed terrain. In the open terrain both approaches generally favour a combined arms approach, however against a pure infantry enemy the proposed approach is willing to sacrifice the attacker's supporting infantry in favour of additional armour assets. This is not captured in the original SFS. Also, against a combined arms enemy the proposed approach suggests either a combined arms response or a purely infantry heavy force can yield similar results. In closed terrain both approaches generally favour a purely infantry response, except that against a purely armoured enemy the proposed approach also suggests that a combined arms attack may yield significantly more attrition to the enemy.

5.8 Extension – Fighting the Unknown

The above experiment concentrated on determining an appropriate attacking force mix against a known enemy in a certain terrain type. While knowledge of the terrain may be foreseeable based on geographic considerations of where likely battles may take place, knowledge of the composition of the enemy in such battles is generally not. To provide advice on appropriate force structuring in these situations, one approach is to consider it within the construct of game theory.

The principles and application of game theory is well described by numerous texts [10] and will not be repeated here, but a simple illustration will be given to extend the above results and to provide a further example of the potential use of such a model as SFS. In these results we will simply use the proposed SFS output data for simplicity.

We will consider each side to have a choice between three strategies regarding its force mix, ranging from a pure infantry (667 infantry assets) through combined arms (20 armour and 333 infantry assets) to a pure armour force (40 armour assets). These are the same strategies the enemy considered separately above. Naturally, a greater number of partitions could (and should) be considered, but to illustrate the principles only three will be considered here. We now provide these as the same choices to the attacker. Table 2 provides the resulting LER under each combination for battles in open terrain.

Table 2 LER Resulting from Battle in Open Terrain for Various Force Mixes to both Sides

Open Terrain		Enemy Force Mix		
		Infantry	**Combined Arms**	**Armour**
Attacker Force Mix	**Infantry**	0.37	0.51	0.02
	Combined Arms	0.39	0.36	0.53
	Armour	3.11	0.10	0.19

For the attacker, the best possible result would be if he used a purely armoured force and the enemy used a purely infantry force, resulting in a LER of 3.11. Conversely, the worst possible result would be if he used a purely infantry force and the enemy used a purely armoured force, resulting in a poor LER of 0.02. These results are intuitively obvious.

To determine the best strategy for the attacker (and in doing so the best strategy for the enemy) the game theory solution is used. The most common criterion for selecting strategies is that of pessimism or the maximin criteria, which represents a conservative decision-making approach. Under this criterion, each side chooses its strategy that offers the best-guaranteed payoff (that is, maximises the minimum payoff for the attacker and minimises the maximum payoff for the enemy), where the payoff is the LER. Applying this criterion to the data in Table 2 we find the preferred strategies for both sides to be to employ a combined arms force with a resulting LER of 0.36.

Table 3 provides the corresponding results for battles in closed terrain. As expected, for the attacker the best possible result would be if he used a purely infantry force and the enemy used a purely armoured force, resulting in a LER of 7.51. Conversely, the worst possible result would be if he used a purely armoured force and the enemy used a purely infantry force, resulting in a poor LER of 0.01. Again, these results are intuitively obvious. Applying the minimax criterion, we find the preferred strategies for both sides to be to employ a purely infantry force with a resulting LER of 0.32.

Table 3 LER Resulting from Battle in Closed Terrain for Various Force Mixes to both Sides

Closed Terrain		Enemy Force Mix		
		Infantry	**Combined Arms**	**Armour**
Attacker Force Mix	**Infantry**	0.32	0.96	7.51
	Combined Arms	0.18	0.35	4.83
	Armour	0.01	0.02	0.33

Finally, if knowledge of the terrain was uncertain then this could be accounted for by taking a probabilistic approach. That is, to take the LER as the weighted average of the data in Tables 2 and 3 with the likelihood of each terrain type determining the weights. For example, if battles in the two terrain types were equally likely to occur, then the combined data would be that as presented in Table 4.

Table 4 Expected LER Resulting from Battle in Either Open or Closed Terrain for Various Force Mixes to both Sides

Unknown Terrain		**Enemy Force Mix**		
		Infantry	**Combined Arms**	**Armour**
Attacker Force Mix	**Infantry**	0.345	0.735	3.765
	Combined Arms	0.285	0.355	2.68
	Armour	1.56	0.06	0.26

Applying the minimax criterion, we find the preferred strategies for both sides in this situation to be to employ a purely infantry force with a resulting (expected) LER of 0.345.

6. Summary and Conclusions

This paper asserts that there is a basic problem that SFS has due to its use of aggregation and disaggregation. Specifically, the degree of imbalance in the anti-armour and anti-infantry capabilities of each side appears to be lost or distorted when a single aggregated Force Ratio is used to compute a total attrition which is then disaggregated into component attrition. Examples are used to show that in certain limiting situations, nonsensical attrition results are predicted.

A simple alteration to the process is suggested as a potential remedy to this situation and the approaches are compared for a typical application whereby optimal force structures are sought. For several situations both approaches suggest identical or similar solutions, although the resulting LERs display a lower level of correlation. Importantly, however, in some situations the new approach suggests somewhat different results. A game theory version of the analysis was provided to illustrate the potential use of models such as SFS in estimating robust force allocations.

The new approach does currently suffer from one deficiency whereby a suitable method for implementing the Participation Factor of Step 14a has not yet been produced.

Ultimately, a validation effort will be required to determine the true extent of the appropriateness of each approach, though it is asserted here that the new approach appears to predict an attrition rate more in line with expectations logically drawn from the underlying data.

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19. ABSTRACT

Situational Force Scoring is routinely used for combined-arms combat adjudication. This paper asserts that there is a basic problem with Situational Force Scoring due to its use of aggregation and disaggregation. Examples are used to show that in certain limiting situations, nonsensical attrition results are predicted. A simple alteration is suggested and the approaches are compared for a typical application whereby optimal force structures are sought. For several situations both approaches suggest identical or similar solutions, although the resulting attrition display a lower level of correlation. Importantly, however, in some situations the new approach suggests somewhat different results. A game theory analysis is also provided to illustrate the potential use of such models in estimating robust force allocations.

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